Use guidance for daily modeled existing and unimpaired flows modeling for California

Bronwen Stanford, Jessi Ayers, and Kirk Klausmeyer, TNC California

April 2026

The daily modeled unimpaired and existing flows datasets were produced by Upstream Tech using a type of artificial neural network known as long short-term memory. Both models were trained on USGS streamgages and descriptor variables included nationally available datasets. Predictions were produced at the subbasin scale and then flows were routed between subbasins and downscaled to produce reach-scale predictions.

A limited number of USGS gages in California were hidden from the model and used to evaluate the performance of both models in ungauged basins. In this document, we discuss the performance of these evaluation gages. For details on modeling methods and model performance, see Upstream's final report (https://rivers.codefornature.org/reports/reach_based_daily_actual_and_natural_flow_predictions_feb2025_report1.pdf). For more details on model performance, see TNC's detailed assessment of the results (https://rivers.codefornature.org/reports/modeling_actual_flows_evaluation_oct2025_report3.pdf).

The LSTM models reported here are the first effort to produce daily predictions at scale for ungauged basins in California that we are aware of. We hope the results will be valuable for other modelers and researchers, and we plan to incorporate it into our own streamflow analyses. However, the outputs have variable accuracy.

We caution practitioners who are interested in actively managing or assessing flows with these predictions to evaluate their specific data and accuracy needs in detail before using this dataset. We recommend that users consider the prediction intervals (e.g., 10^{th} - 90^{th} percentile) to understand model uncertainty and review both reports and the information below.

To further guide users of the data, we have highlighted some of the known limitations of the dataset with examples below. Please contact Jessica.Ayers@tnc.org or Bronwen.Stanford@tnc.org with any further questions.

1. Low performance in rivers with low annual precipitation and high groundwater dependence (Unimpaired and Existing models)

Low flows, especially below approximately 1cfs, were consistently difficult for the model to estimate accurately. This challenge is common across many hydrologic and statistical models because discharge is difficult to measure at extreme low flows. However, we also found that the models poorly represented baseflow in southern California and places with low precipitation and in basins with large groundwater inputs.

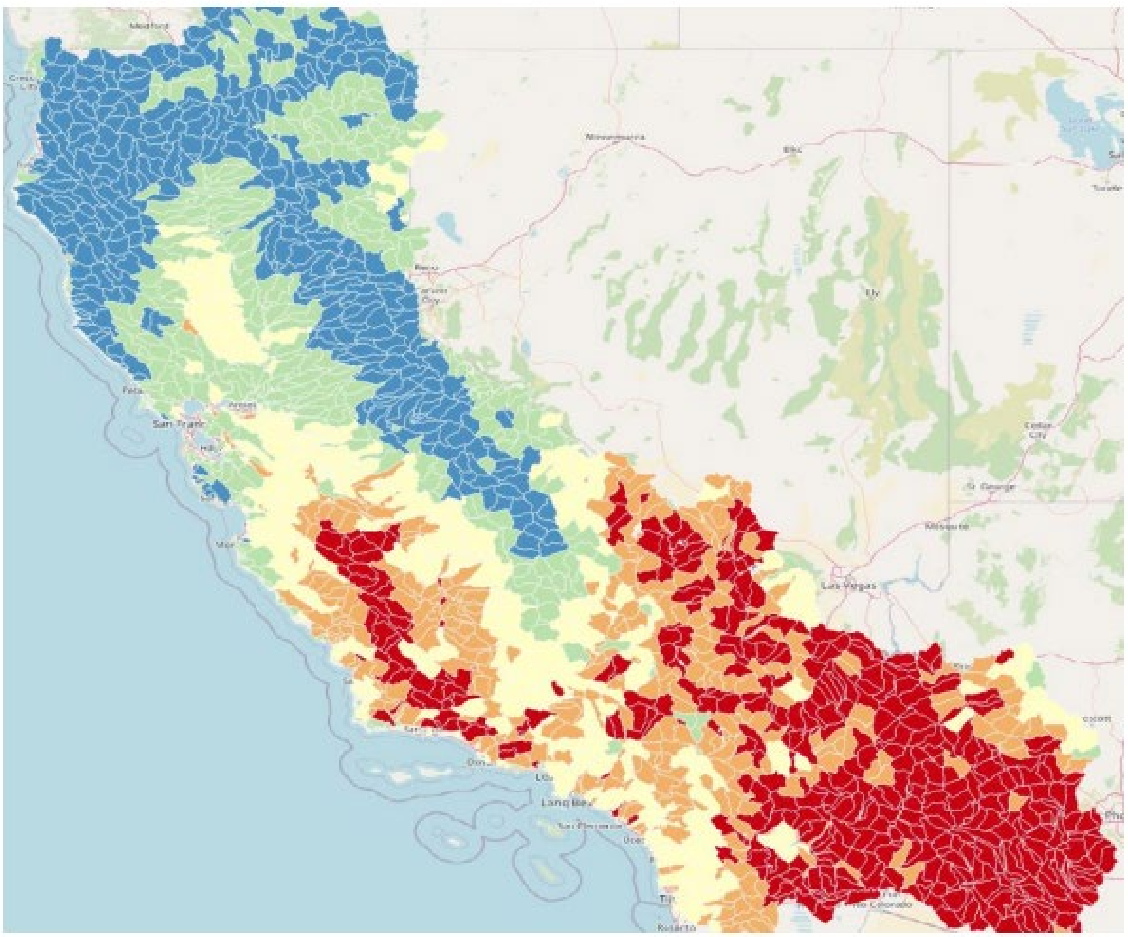

Figure 1: Sub-basins showing the normalized 75th percentile of flow. Red basins have a normalized flow below 0.0005 and are intermittent rain areas with few validation sites and poor performance. Yellow and orange have decent performance while green and blue were observed to have good model performance.

2. Inconsistent patterns of performance (Unimpaired and Existing models)

In general, performance for both models was better in coastal northern California and worse in southern California. However, we were not able to identify areas with high model performance confidently because there was still variation in performance given stream size and/or land use and human impacts. For example, within the north coast region, the wettest part of the state, performance of both models was highly variable, from an NSE of -71.28 to 0.82 and percent bias of –569.57 to 212.62.

Further characterization could better reveal patterns driving performance, but we were unable to develop a clear grouping that would enable the user to feel confidence in any subset of data for ungauged reaches. Therefore, users should practice caution at all ungauged sites.

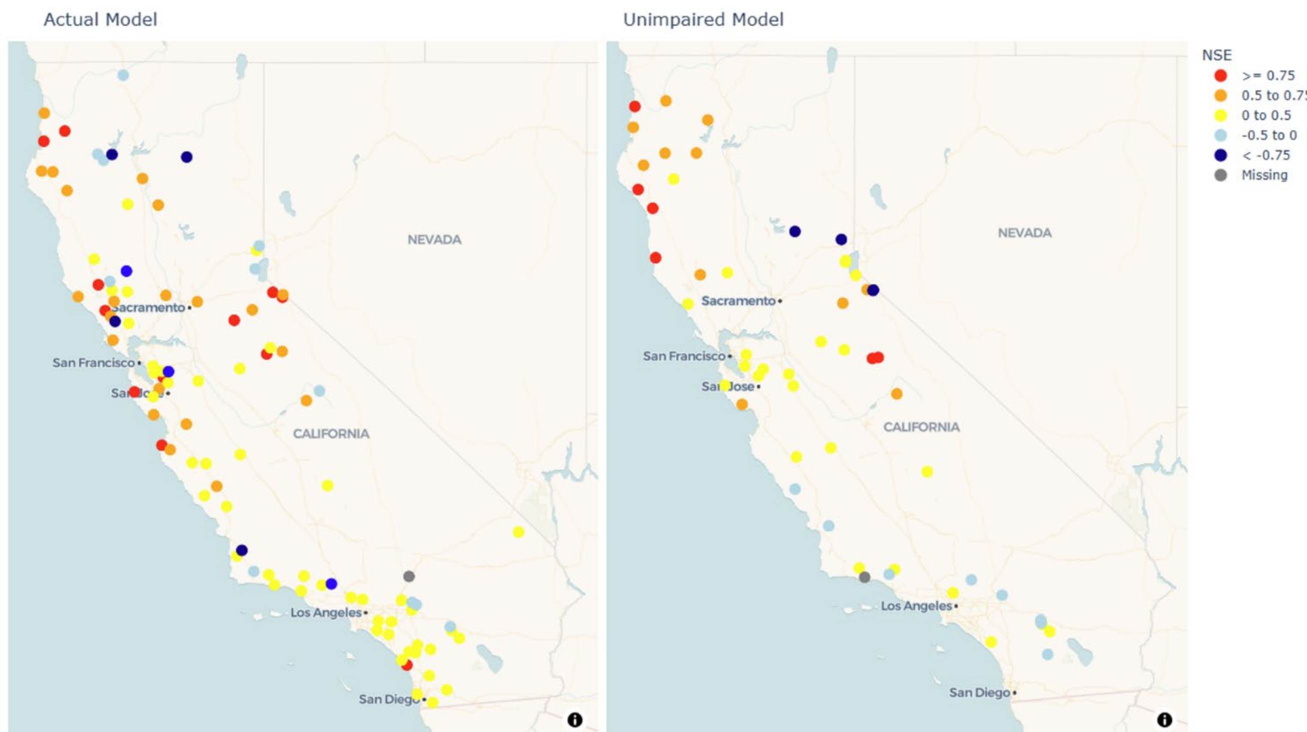

Figure 2: Maps displaying the NSE values for daily flows at the evaluation 98 and 54 USGS streamgages for the Modeled existing and Unimpaired model, respectively.

3. Modeled Unimpaired and Existing flows models are not comparable

Although the modeled existing and unimpaired models were developed using the same methods and approach, they were trained on distinct training datasets. The unimpaired model was trained on USGS minimally disturbed gages, and the existing model was trained on disturbed USGS gages. Additionally, the existing flows model had an additional suite of predictor variables.

The LSTM modeling process is naturally stochastic, and results from even an identical set of model inputs might be different. As a result, users should not expect that the modeled existing flows can be directly compared with the unimpaired model to understand flow alteration. For example, in some diversion-based systems the unimpaired model had lower flows than the modeled existing flows model, which is not realistic.

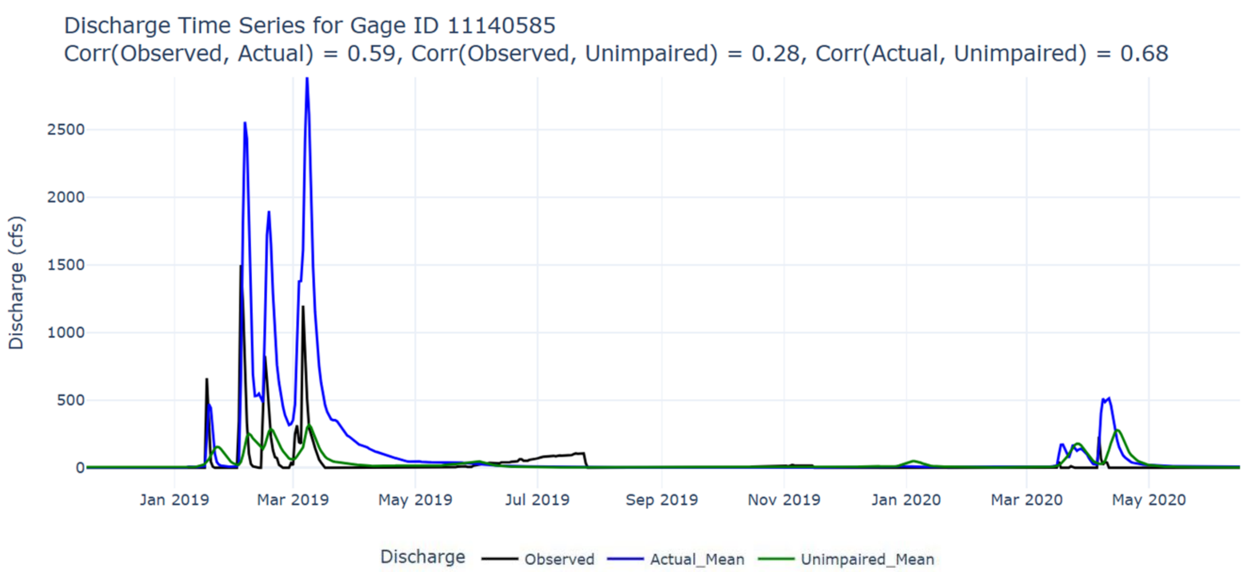

Figure 3: USGS gage 1140585 (Santa Maria River) showing the observed (black) streamflow for January 2019 to May 2020. The "Actual" or Existing modeled mean (blue) is compared to the Unimpaired modeled mean (green).

4. Underprediction, particularly of peak flow events (Existing and Unimpaired models)

We saw negative bias at most evaluation gages for both models, which indicates that the models underpredicted observed values on average. In particular, we found underprediction of peak flow events was common. Figure 4 shows an example on the Eel River near Fort Seward shows consistent underprediction of winter storm flow event magnitudes by both models.

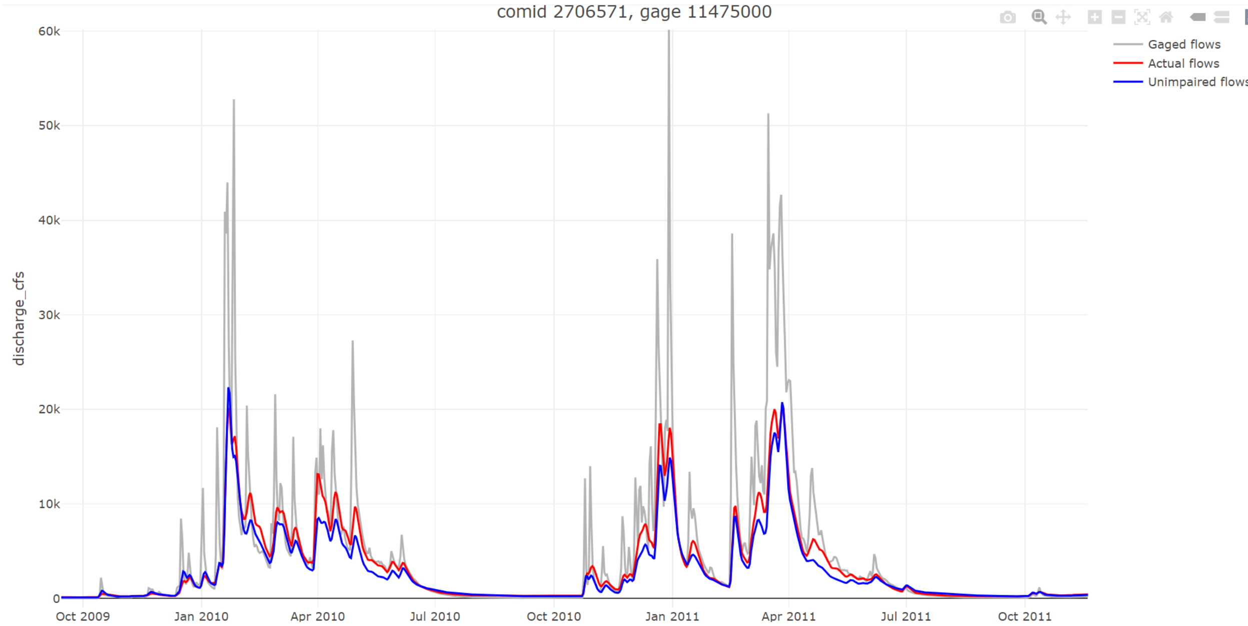

Figure 4: Daily streamflow for gage 11475000 Eel River. The observed is shown in grey while the Existing streamflow predictions are in red and the Unimpaired predictions are shown in red.

5. Overprediction of dry season flows (Existing and Unimpaired models)

We did not rigorously evaluate patterns of overprediction of baseflow, but we found many instances where the model overpredicted dry season flows, particularly in drier years. For example, this small drainage (north fork Navarro)

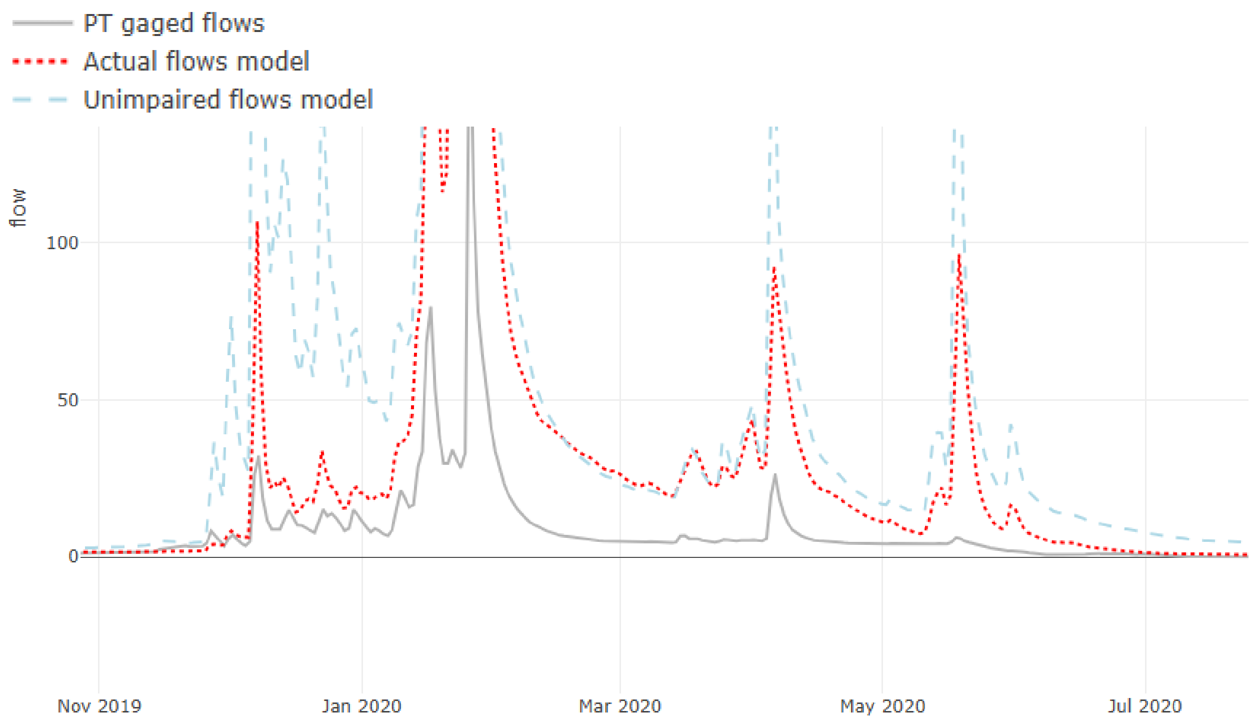

Figure 5: North Fork Navarro stream gage where the grey line is the observed flow from November 2019 to July 2020. The red line shows the modeled Existing flows (Actual) and the blue light shows the modeled Unimpaired flows.

6. Inability to accurately predict effect of flow diversions or augmentation (Existing model)

A major challenge for the existing flows model was learning to predict human alterations to instream flow, including distributed small-scale impacts, such as diversions and discharges. In regions with widespread small surface water diversions and groundwater pumping (the north coast), the modeled existing flows model often produced higher predictions than the unimpaired flows model, suggesting that the model was unable to accurately predict the presence of these diversions. In Figure 6 the Cuyama River flows are illustrated with the Existing and Unimpaired modeled flows. This watershed has no regulation upstream but has groundwater pumping from wells along the stream upstream of the gage. In some years we see the model does well and in others, the model over predicts, especially in dry years where pumping is more prevalent.

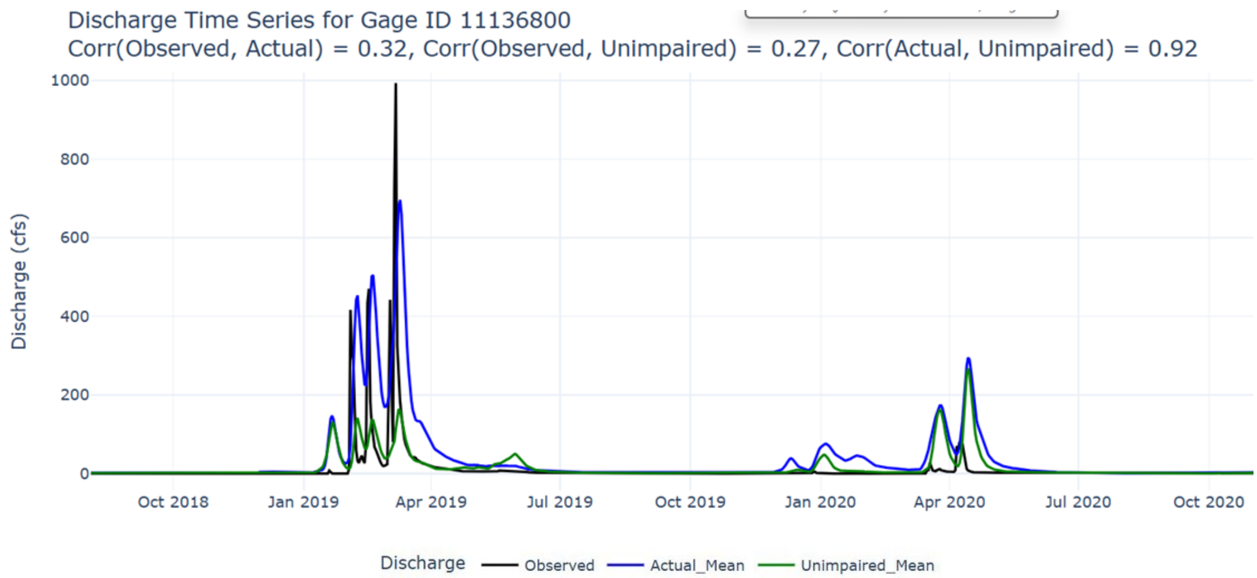

Figure 6: USGS gage 11136800 Cuyama River near Santa Maria, CA. The river has no regulation upstream but has pumping from wells along the stream for irrigation several thousand acres in Upper Cuyama Valley. The black line shows the observed streamflow for January 2007 to January 2009. The "Actual" or Existing modeled mean (blue) is compared to the Unimpaired modeled mean (green).

7. Limited ability to predict flows below reservoirs (Existing model)

The model also struggled to accurately represent the effect of reservoir operations on flow. Flows below reservoirs are particularly difficult to model on ungauged rivers. Often, reservoir operations are managed using operating protocols that seek to balance flood risk with the beneficial uses of the reservoir (e.g., hydropower production, irrigation deliveries). The operation of each reservoir can be different, given the constraints and priorities for that reservoir. There is no accessible national dataset detailing operations for each reservoir, so the model had limited opportunities to infer operating priorities. We expect that this lack of consistent datasets representing modeled existing reservoir operations will be a challenge for any future modeled existing flows modeling efforts as well.

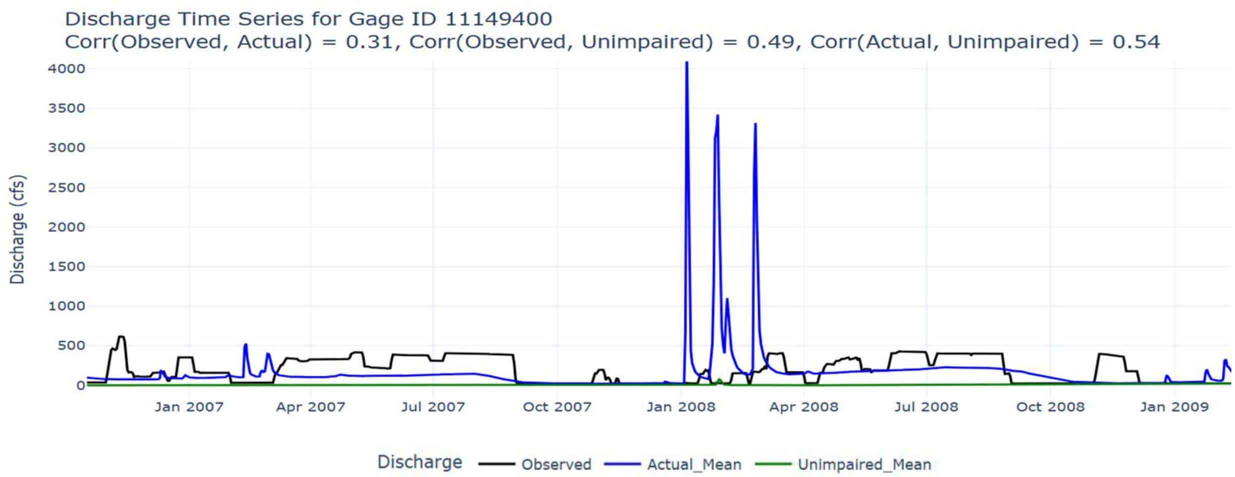

Figure 7: USGS gage 11149400 below Nacimiento Dam near Bradley, CA. The black line shows the observed streamflow for January 2007 to January 2009. The “Actual” or Existing modeled mean (blue) is compared to the Unimpaired modeled mean (green).

8. Observed gage data is not directly incorporated into the model (Existing model)

One innovation for this model was planned to be the incorporation of modeled existing gage data into the final output where it exists, to improve all downstream predictions. However, this was only accomplished at a small number of gaged locations in the southern half of the state. Users should not expect to see improved predictions downstream of USGS gages in the northern half of the state.

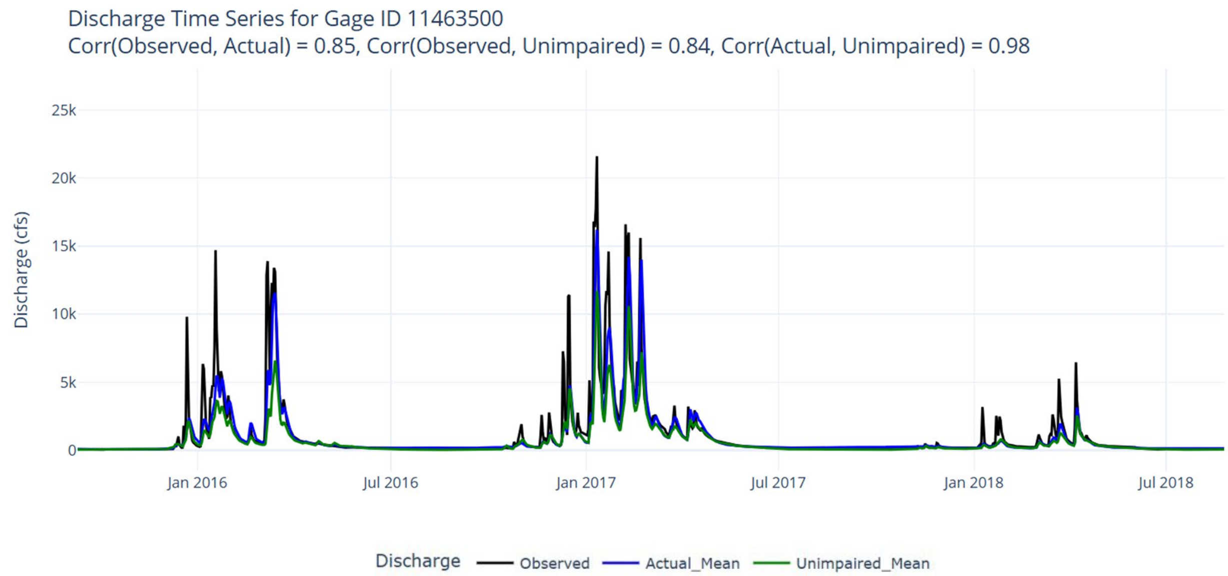

Figure 8: USGS gage 11463500 Russian River near Geyserville, CA. The black line shows the observed streamflow for January 2016 to July 2018. The Actual is the Existing modeled mean (blue) and green is the Unimpaired modeled mean.